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The Current Status of Open Cardiac Surgery

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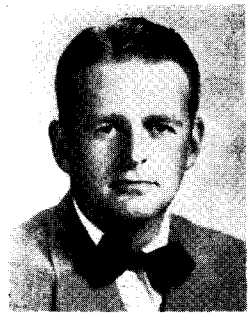

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THE inner surfaces of the chambers of the heart are the last anatomic areas of the body to yield to safe direct-vision surgical intervention. In the past five years, two entirely different methods to achieve this have been developed to the stage of practical clinical application. Thus, today, no portion of the human body defies surgical exposure.

The implications of this accomplishment on the future treatment of various forms of heart disease are obviously great, since both hypothermia and cardiopulmonary bypass are only in their infancy in terms of application to the technical problems posed by specific disease states. Significant advances in surgical treatment of various forms of heart disease can be confidently expected for years to come.

At present it would appear that hypothermia is the safer of the two technics, but it also has stricter limitations. Since this method received clinical trial earlier, it is not surprising that it has achieved a slightly more mature state of development. This is not, however, to say some pump oxygenators may not soon equal or exceed it in terms of risk; it is to be hoped that both technics will soon be essentially without risk. I shall outline some experience with both methods, and indicate some of the problems yet to be overcome.

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Hypothermia

Stimulated by the report of Bigelow and associates[1] in 1950, hypothermia has been and is at present under continuing investigation in the Halsted Laboratory for Experimental Surgery at the University of Colorado. It was early observed that general hypothermia was attended by a high mortality because of severe myocardial arrhythmias (especially ventricular fibrillation) and because of serious disturbances in the clotting mechanism. Extensive experimental and clinical observations over the past five years have essentially eliminated both these hazards. We feel that the risk of hypothermia per se, as currently employed in this clinic, is in the neighborhood of zero.

TABLE 1

PROGRESSIVE INCIDENCE OF SIGNIFICANT CARDIAC ARRHYTHMIAS IN 265 CASES IN WHICH HYPOTHERMIA WAS USED

	FIBRILLATION	DEATH	STANDSTILL	DEATH
First 100 cases	15	12	7	1
Second 100 cases	8	4	1	1
Last 65 cases	1	0	0	0

The following details in the management of clinical hypothermia for cardiac surgery appear important in promoting the safety of the method.

1. The range of the lowest rectal temperature achieved is 30 to 32° C. Circulatory arrest is performed at this temperature.[2] This limitation in degree of hypothermia is extremely important.

2. Cooling is accomplished simply and by design by immersion in ice water. There appears to be some rationale in cooling the peripheral tissue ahead of the heart and other vital organs.[3]

3. Throughout the entire procedure, a deliberate respiratory alkalosis is maintained by hyperventilation.[4,5]

4. Throughout the course of the cooling, operation and warming, dextrose is administered intravenously. Evidence is increasing that intravenous nutrients have a beneficial effect on the myocardium in hypothermia.[6]

5. The first two units of blood used during operation are heparinized, having been freshly drawn in plastic bags. The presence of platelets, fibrinogen and other enzyme elements of the clotting mechanism, together with the absence of citrate, are considered helpful in avoiding the bleeding diathesis of hypothermia.[7] Transfusion is given freely because a low blood volume is poorly tolerated in hypothermia.[8]

6. A bilateral sternum-splitting incision is always used in order to achieve adequate exposure and allow proper positioning.[9]

7. Great care is taken to position the patient so that the cardiotomy is in the uppermost portion of the heart, thus materially reducing the risk of air embolism occurring in the coronary arteries.[10]

8. After the establishment of inflow occlusion to the heart the coronary circulation is perfused with 1 to 2 cc. of 1:4000 PROSTIGMIN® in order to slow the heart. The decreased metabolic needs of the slowly beating heart apparently are important in reducing the risk of ventricular fibrillation.[11-13]

9. The root of the aorta is always clamped (except in operations for aortic stenosis) to prevent coronary blood flow during occlusion. This helps avert coronary air embolism, maintains bradycardia, and diminishes the coronary return to the heart, thus insuring a dry operative field.[14]

10. The period of circulatory arrest must not exceed six minutes. If more time is needed to complete the procedure, the operation should be interrupted and the circulation restored. A second period of occlusion can then be instituted after an appropriate interval to complete the procedure. The principle of multiple short occlusions allows at least 10 minutes of safe intracardiac time.[15]

11. Warming is achieved by diathermy, which is a form of internal warming. There appears to be some rationale for rewarming vital internal organs before peripheral tissues.[3]

Careful observation of these considerations reduces the mortality rate of hypothermia itself to a level that is essentially negligible. For example, the incidence of serious cardiac arrhythmias in our series of patients is given in table 1. The incidence of disturbances in the clotting mechanism is given in table 2. It is clear that as the limitations of the methods and better control of the unusual physiology were learned the risk has steadily decreased.

TABLE 2

PROGRESSIVE INCIDENCE OF CLOTTING DISTURBANCES DURING OR AFTER HYPOTHERMIA

	BLEEDING	THROMBOSIS	DEATH
First 100 cases	4	2	6
Second 100 cases	3	2	5
Last 65 cases	0	1	0

TABLE 3

PROGRESSIVE MORTALITY FOR ALL PATIENTS UNDERGOING OPEN CARDIAC PROCEDURES DURING HYPOTHERMIA (180 CASES)

	DEATHS	
	Number	*Per Cent*
First 60 cases	12	20
Second 60 cases	6	10
Third 60 cases	3	5

In the last 65 cases, not a single death was attributable to either ventricular fibrillation or a disturbance of the clotting mechanism.

The effect of better over-all management of hypothermia on the mortality rate of open heart operations is seen in table 3. Of course, better selection of patients and improving technic with increasing experience may play a part in the trend of these figures, but irrespective of the relative importance of various factors it is gratifying that there has not been a single death among the last 41 patients undergoing bilateral thoracotomy and open cardiotomy during hypothermia.

In view of this experience, we feel at present that those open cardiac procedures which can be technically achieved in 10 minutes of direct-vision time should be done during circulatory occlusion under hypothermia, since the method itself is so safe.

The following diseases are examples of lesions for which the open operation is clearly preferable to blind technics and the procedure can be done adequately within the time limit.

1. Pulmonary valvular or infundibular stenosis occurring as a single lesion.
2. Atrial septal defect (secundum).
3. A combination of pulmonary stenosis and atrial septal defect (trilogy of Fallot).
4. Aortic stenosis.

Both valvular and infundibular pulmonic stenosis, occurring as isolated lesions, are readily amenable to plastic repair. The results of open intervention in restoring normal hemodynamics and obliterating the pressure gradient have been very satisfactory.[16] Since the mortality has been nil in this group, we now recommend operation to any young patient whose pressure in the right ventricle exceeds 70 mm. Hg, irrespective of whether or not he has had any symptoms relative to the heart. Table 4 shows our total cumulative experience with these two lesions. With the risk rate so low and the results so satisfactory following open operation during hypothermia, it seems unwise at this time to recommend either a closed procedure or use of the pump oxygenator, with its greater risk.

Atrial septal defect of the so-called secundum type is a lesion complicated by many associated variations. Aberrant pulmonary venous drainage into the right auricle, multiple septal defects, unusual prominence of the valve of the inferior vena cava, and associated patent ductus arteriosus all commonly participate in this malformation. With such complexities it seems hardly necessary to mention the superiority of an open technic for treatment. In spite of its variety it is uniformly possible to repair the lesion in such a fashion that the pulmonary veins are transplanted to the left side of the repair in less than 10 minutes of operating time. Table 5 outlines our experience with this operation. In view of the fact that the last 41 patients with atrial septal defect have undergone a curative procedure without mortality, we are currently extending our

TABLE 4

RESULTS OF DIRECT-VISION REPAIR OF PULMONARY STENOSIS DURING HYPOTHERMIA (INTACT SEPTA)

TYPE	CASES	CURED	IMPROVED	DEATHS
Valvular	34	32	2	0
Infundibular	4	4	0	0

TABLE 5

RESULTS OF DIRECT-VISION REPAIR OF ATRIAL SEPTAL DEFECT (SECUNDUM) DURING HYPOTHERMIA

	CURED	DIED
First 43 patients	36	7 (16%)
Last 41 patients	41	0

TABLE 6

RESULTS OF DIRECT-VISION OPERATION DURING HYPOTHERMIA IN TRILOGY OF FALLOT

CASES	OPERATIONS	TOTAL CURE	IMPROVEMENT	DEATH
16	18	6	7	3

indications for operation in young persons with this disease. We believe at present that all patients with atrial septal defect (secundum) should have operation when the diagnosis is established, irrespective of the presence or absence of symptoms, gross cardiac enlargement, or other objective findings. A major contraindication to operation is reversal of the shunt with consequent cyanosis. In this respect, therefore, the indications for surgery are essentially similar to those for patent ductus arteriosus.

The combination of atrial septal defect and pulmonary stenosis (trilogy of Fallot) presents interesting therapeutic problems. In 15 of our 16 cases the shunt preoperatively was right to left, and the patient was cyanotic, in some instances extremely so. Our initial impression was that if adequate relief of the pulmonic stenosis were achieved the atrial septal defect might close spontaneously. However, in some cases cyanosis has persisted while in others a conversion of the shunt to a left-to-right direction has resulted in cardiomegaly and even cardiac failure. Two of these earlier patients, therefore, have undergone a second hypothermic procedure to close the auricular septal defect. In our last four patients we performed a two stage curative procedure at a single session, first opening the pulmonary valve and then suturing the atrial septum at a second occlusion. Our cumulative experience with this malformation is seen in table 6. Some of the earlier patients with only a single stage may eventually need closure of the atrial septal defect. In six of the surviving patients the circulatory system has been restored essentially to normal.

More recently we have explored the possibility of transferring our technic for pulmonic obstruction to operation on the aortic valve.[17] Exposure of the ostia of the coronary arteries to room air did not prove a serious deterrent, as methods for avoiding coronary air embolism were developed. The risks of this procedure have proved to be largely technical, since the need for much greater care in avoiding regurgitation of the aortic valve following manipulation limits the operation and extends the operative time. Nonetheless, the results in a small series to date have been sufficiently satisfactory to warrant continuation of the technic. These results are shown in table 7. In our opinion the open procedure is so superior to the digital and blind instrumental technics previously available that operative intervention in rheumatic aortic stenosis is justified much earlier, before there is extensive calcification of the valve. In addition, it is suggested that congenital aortic stenosis is more common than generally supposed and that, whether the obstruction is valvular or subvalvular in position, open operation is indicated when left ventricular strain is present, with or without subjective symptoms.

Total Cardiopulmonary Bypass

Many lesions require much more operating time than that currently permitted by hypothermia. For these, the pump oxygenator using total cardiopulmonary bypass is the method of choice. The variety of oxygenators and pumps currently in use throughout the world attests to the fact that the best design for such an instrument has yet to be developed. The problems associated with total bypass are multiple. Blood procurement and crossmatching, rate of flow, type of pulse, adequacy of oxygenation and extraction of carbon dioxide, avoidance of air embolism, aberrations in me-

TABLE 7

RESULTS OF DIRECT-VISION REPAIR OF AORTIC STENOSIS DURING HYPOTHERMIA

	CASES	IMPROVEMENT	DEATH
Congenital			
Valvular	10	9	1
Subvalvular	3	1	2
Acquired	2	2	0

tabolism, difficulties in sterilization, protection of the formed elements of the blood, and avoidance of interference with the clotting mechanism are only a few. Moreover, all these difficulties are compounded with time; the longer the perfusion, the greater the risk of serious or fatal physiologic deviation. Thus the very essence of the need for pump oxygenation, a prolonged operative time, imposes a condition which raises the risk. We know of no pump oxygenator as yet which has a risk rate approaching that of hypothermia.

Our earlier experience with a bubble-type oxygenator was extremely unsatisfactory. Damage to the cells, disturbance in clotting, and diffuse cerebral damage presumably from multiple small emboli were associated with inadequate flow rates. For these reasons we turned to a screen-type oxygenator with roller pumps, a combination which had long been studied by Gibbon,[18] and was subsequently further refined by Kirklin et al.[19] After extensive laboratory trial, this instrument received clinical trial in 13 cases of advanced pulmonary hypertension associated with interventricular septal defect. In most instances it was possible to close the defect by direct suture, but in three it was necessary to plug the defect. One patient, undergoing operation for the second time, had profuse bleeding during and after heparinization. Her hemorrhagic diathesis eventually proved fatal. Another child died quite unexpectedly of heart block a few hours after operation. The other 11 patients have done well, but the effectiveness of the repair and its influence on the advanced pulmonary vascular disease remain to be studied. It appears that the pump oxygenator system we are using is adequate although still replete with danger as bypass is prolonged. It will remain the subject of continuing laboratory investigation. We intend to extend its use to more complicated lesions such as transposition and tetralogy and to continue work on its potential use in acquired valvular disease.

Summary

Our experience with the current methods available for open cardiac surgery is briefly reviewed. At present, after a broad experience, we consider hypothermia to be essentially without risk and therefore the method of choice for intracardiac procedures which can be accomplished in 10 minutes or less. Our screen oxygenator in association with roller-type pumps has proved adequate for total cardiopulmonary bypass. The risks of this instrument have not been thoroughly assessed, but application to a broader spectrum of intracardiac conditions seems justified on the basis of our early experience.

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